

# POLYISO ROOF INSULATION:

## ZERO OZONE DEPLETION POTENTIAL, LONG-TERM THERMAL STABILITY, AND A FOUR-YEAR TRACK RECORD

BY RICHARD ROE

**W**e all remember Y2K when most of our computers were predicted to fail, unable to recognize the year 2000. Warnings from CNN and the newspapers were seemingly endless, explaining in ever-greater detail the dire consequences we would face, including crashing computers, disappearing bank accounts, and disruption of electricity, natural gas, and water supplies. As a result, people were busy stuffing Y2K cash in their cookie jars and buying bottled water, canned food, portable heaters, and other survival supplies. It was a relief to learn that, at the stroke of midnight on New Year's Eve, 1999, nothing happened. Similarly, some in our industry seem to share this fear that a mysterious, ominous event is about to plague the roofing industry at midnight on 12/31/02, when overnight the blowing agent in polyiso will change. What will happen when the "new" polyiso arrives? Will it change roofing as we know it? Fortunately for our industry, these questions were answered four years ago.

Since the manufacture of polyisocyanurate (polyiso) foam plastic insulation has historically included an ozone-depleting blowing agent, it is subject to the regulations of the Montreal Protocol as implemented by the U.S. Environmental

Protection Agency (EPA). As a result, the polyiso industry is experiencing its second mandated blowing agent conversion in the last nine years. On 1/1/03, the production and importation of the chemical blowing agent (HCFC-141b) used in the manufacture of polyiso foam insulation is scheduled for phase out in the U.S. This article presents environmental issues responsible for these regulations and a chronology of early product development efforts undertaken by Atlas Roofing Corporation, which introduced in 1998 the first zero ozone-depleting polyiso roof insulation available in North America. It will also explain the function of the blowing agent and its influence on dimen-

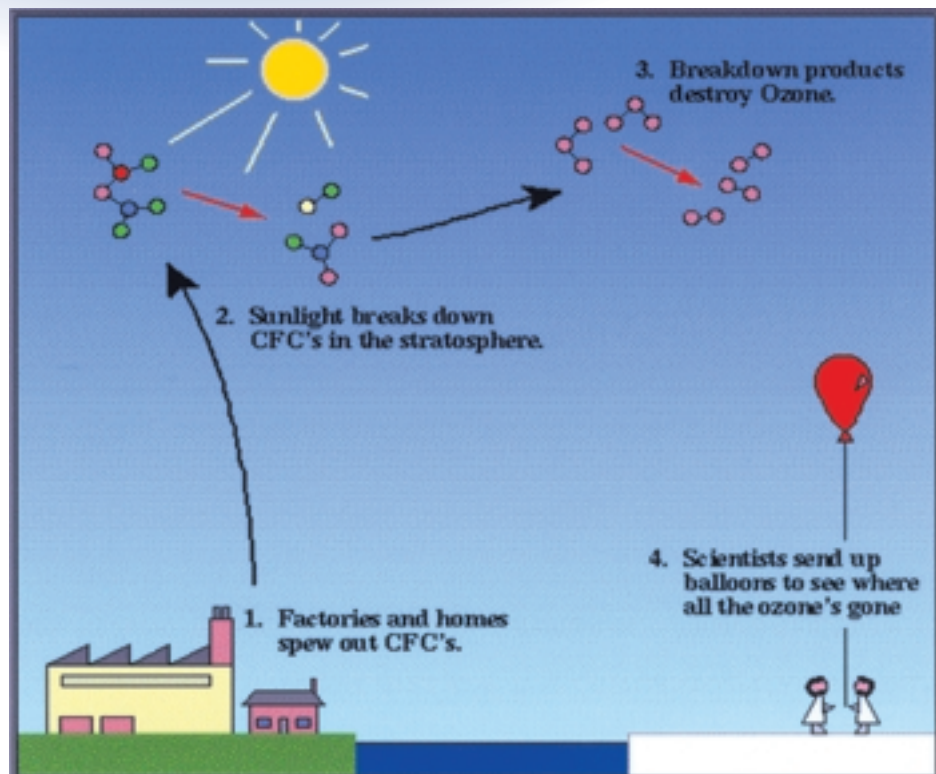
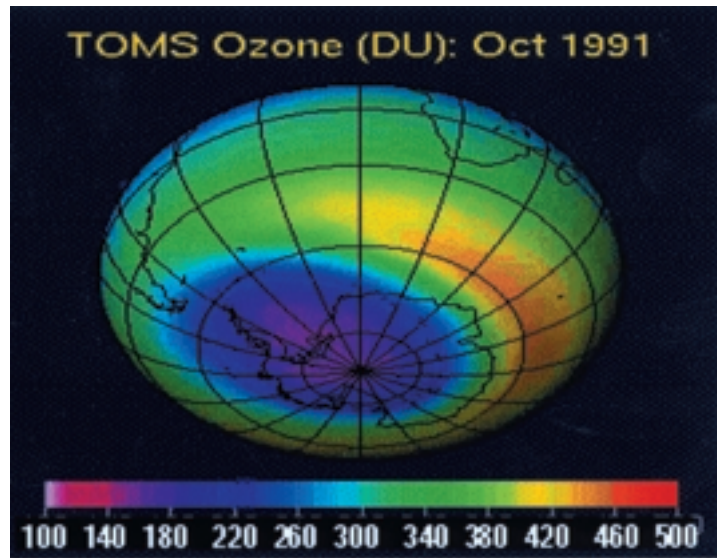
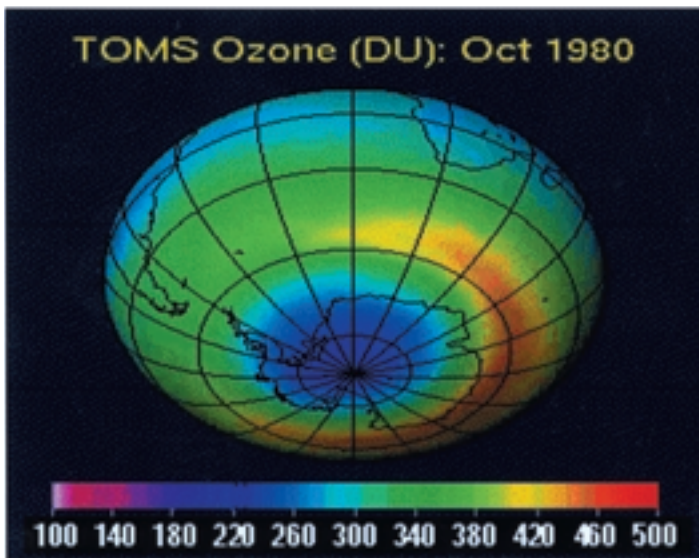


Figure 1: In the 1970s, scientists were alarmed by the apparent depletion of the ozone layer above Earth.



Figures 2 and 3: Total Ozone Mapping Spectrometer (TOMS) graphs show the progressive depletion of the ozone layer from 1980 to 1991.

sional stability and thermal performance, including long-term thermal resistance, as explained in the literature and illustrated by third-party laboratory test data.

### Background on Environmental Issues

The stratospheric ozone layer extends from approximately 6 to 30 miles above the Earth's surface and protects life from potentially deadly UVB, a specific band of UV (ultraviolet) radiation. The depletion of this protective layer is predicted to lead to increased cases of skin cancer, plant disease, related ecological imbalance, and decreased reproductive capacity of marine life, including fish, shrimp, and crab. In the 1970s, scientists were alarmed by the apparent loss of ozone detected in some areas above the Earth and by the growing evidence that ozone depletion was directly related to the release of certain human-made chemicals into the atmosphere (Figure 1). Governments around the world reacted with surprising speed.

In 1977, the United Nations Environment Programme (UNEP) began to address the issue of CFCs and ozone layer depletion. The next year, the U.S. EPA banned aerosol spray products containing CFCs (chlorofluorocarbons), followed by Canada in 1980. The Vienna Convention for the Protection of the Ozone Layer was held in 1981 and agreed upon in 1985. Despite very general language in this agreement, momentum was building, propelled especially by the discovery of the ozone hole over Antarctica. The NASA Total Ozone Mapping Spectrometer (TOMS) graphs shown in Figures 2 and 3 help to explain the international concern regarding ozone depletion. In 1957, the ozone layer was measured at 330 Dobson Units (DUs), which indicate its depth (Figure 4). By 1980, the depth was measured at 227 DUs (Halley)<sup>1</sup> as shown in Figure 2. The 1991 TOMS graph shows the growth of the hole, encroaching by then on the southern portion of South America, and the depth of the hole had been reduced as well from 227 to 140 DUs. In other words, the ozone layer had become progressively thinner.

This flurry of international activity culminated in The Montreal Protocol on Substances that Deplete the Ozone Layer, the most recognized environmental treaty to date, adopted in

1987 and effective in 1989. The Montreal Protocol has been ratified so far by 183 nations, including highly industrialized nations such as the U.S., Canada, and Germany, as well as diverse nations like Albania, Barbados, China, Croatia, Russia, Venezuela, and Zimbabwe (UNEP).<sup>2</sup>

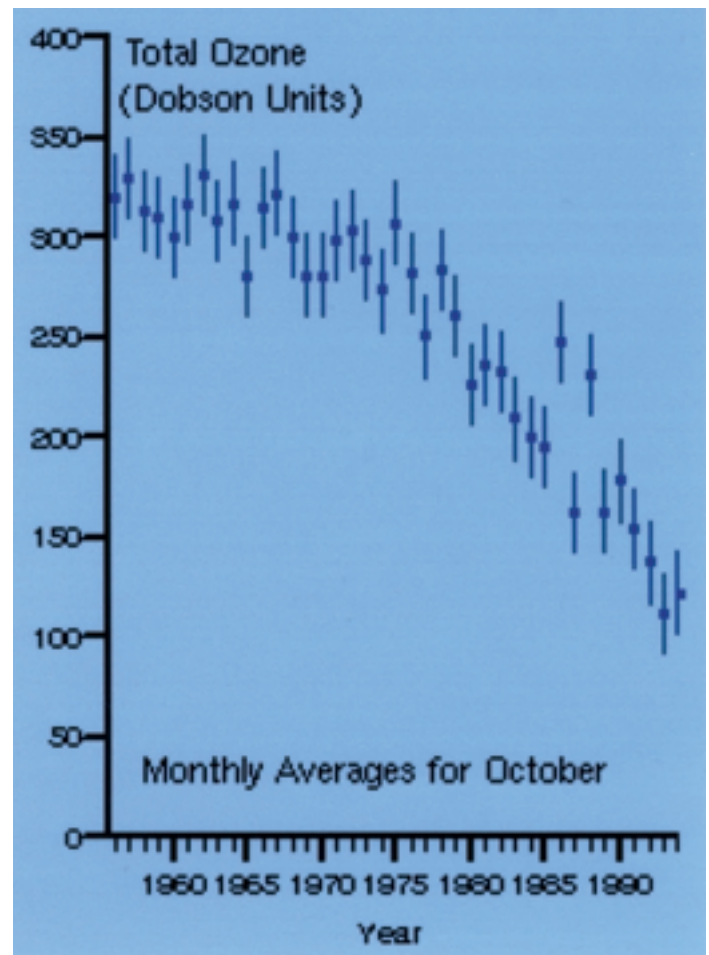


Figure 4: By 1980, the ozone depth was measured at 227 Dobson Units. In 1991, the hole had been reduced to 140 DUs, becoming increasingly thinner.

## The Montreal Protocol and Foam Plastic Roof Insulation

Polyiso foam is produced from the chemical reaction caused by mixing primarily isocyanate, polyester polyol, and a blowing agent, although other ingredients, such as catalysts and surfactants, are also necessary. During this exothermic (heat producing) chemical reaction, temperatures of the foam are more than sufficient to cause the liquid blowing agent to boil and vaporize, expanding the foam and creating the millions of gas-filled cells that provide polyiso's high thermal resistance or R-value. The blowing agent is the chemical ingredient regulated by the U.S. EPA.

Since foam manufacturing represented between 14 and 18% of the total quantity of ozone depleting chemicals



Figure 5: Sources believed to harm the protective ozone layer in 1994 included foam products, at 14.3%.

used in the U.S. when the Montreal Protocol was ratified (Figure 5), this industry, including polyurethane, polyiso, and extruded polystyrene, became subject to new environmental regulations (Federal Register).<sup>3</sup> The Montreal Protocol classified Controlled Substances as Class I, which included CFCs, and Class II, which included HCFCs (hydrochlorofluorocarbons). These classes were determined based on the ozone depletion potential (ODP) of the controlled substances. Class I substances had higher ODPs and were the first substances mandated for phase out by the Montreal Protocol.

Since most of the foam plastic roof insulation industry used CFCs as blowing agents, it faced its first conversion in the early '90s when CFC-11 and CFC-12 were replaced in foam plastic insulations by hydrochlorofluorocarbons (HCFC-141b in polyurethane and polyiso and HCFC-142b in extruded polystyrene). Although HCFCs had lower ODPs than CFCs, they were allowed solely as temporary substitutes for CFCs as the industry searched for a substitute with zero ODP.

Table 1 shows the relative ODPs and global warming potentials (GWPs) for the CFCs banned in the early '90s; the three HCFCs considered "most damaging" by EPA (some manufacturers use

Chemical Blowing Agent	Atmospheric Lifetime in Years	Ozone Depletion Potential	Global Warming Potential	U.S. EPA Phaseout Date
CFC-11 (polyiso)	45	1.0	4000	1/1/1994
CFC-12 (extruded polystyrene)	100	1.0	8500	1/1/1994
HCFC-141b (polyiso)	9.2	.11	630	1/1/2003
HCFC-142b (extruded polystyrene)	18.5	.065	2300	1/1/2010
HCFC-22	11.8	.055	1700	1/1/2010
HC (polyiso)	few days	0.0	0.0*	NA

Table 1. Data obtained from EPA website [www.epa.gov/ozone/odp.html](http://www.epa.gov/ozone/odp.html). Links to further information can be found there. The international community recognizes and uses these numbers.

\*GWP for hydrocarbons is negligible and considered zero by the U.S. EPA.

HCFC-22 as a secondary co-blowing agent); and hydrocarbons (HCs), now available in certain polyiso roofing and sidewall sheathing products across most of the U.S. and Canada. Although not addressed by the Montreal Protocol, global warming, if unchecked, is predicted to lead to severe, disruptive, and ultimately calamitous climate change (Figure 6). This is being addressed by the international community through the Kyoto Protocol. GWPs are based on an index of 1.0 for Carbon Dioxide (CO<sub>2</sub>).

That conversion from CFCs to HCFCs in 1993 represented only the first step toward zero ozone depletion potential

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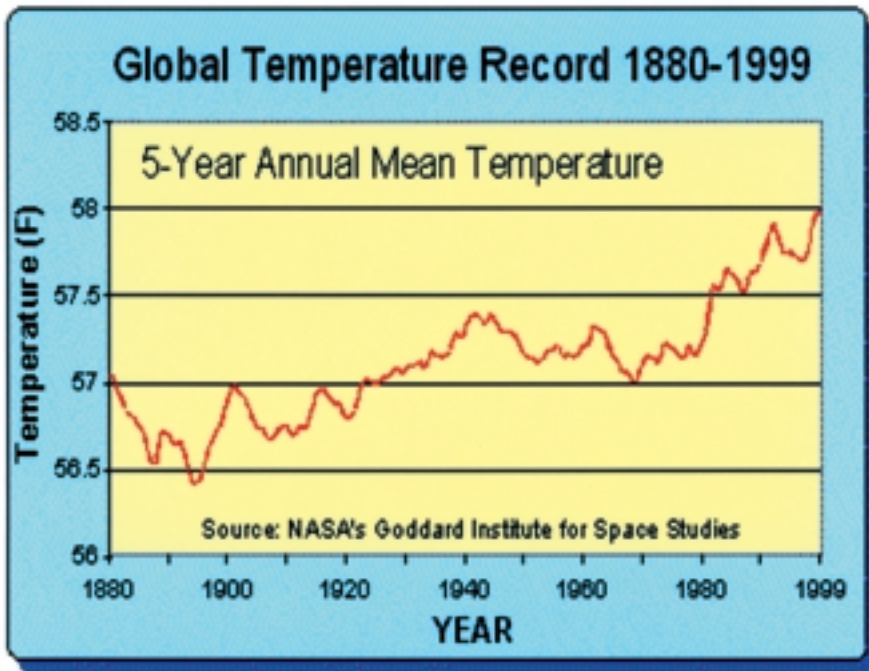


Figure 6: Unchecked global warming could lead to calamitous climatic changes.

(ODP) for foam plastic roof insulation products blown with low conductivity gases. The accelerated U.S. EPA phase out deadline for HCFC-141b will occur at the close of 2002, just nine years from the first conversion. Ozone depletion and global warming potential for certain other foam plastic roof insulation products

will not reach zero until 2010, unless manufacturers choose to convert to zero ODP and zero GWP blowing agents prior to that date.

### Atlas Roofing Corporation and Early R&D

When a blowing agent in foam plastic insulation is changed, important properties of the product can be affected, such as thermal conductivity and dimensional stability, among others. It can also cause adjustments to process variables, according to the manufacturing site and type of equipment used. These adjustments could include chemical reactivity and flow rates, blending, curing, chemical and laminator temperatures, and line speeds, some or all of which may be required for optimum formulation performance in the finished product. Therefore, a great deal of time and capital investment are necessary to research, develop, and produce zero ozone-depleting products suitable for use in roof systems.

This issue has been more difficult during the second conversion, requiring additional time for adequate R&D because chemical suppliers did not seem to have a clear solution to offer manufacturers, unlike the first conversion in the early '90s. At that time, HCFC-141b was basically a "drop-in" replacement for CFC-11, requiring little or no special equipment conversion, and it generally seemed to meet other desirable characteristics. Although the

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- Third Generation Blowing Agents: Desirable Characteristics**
- 0.0 ODP (required by Montreal Protocol)
  - Non-Toxic
  - Low Thermal Conductivity
  - Economically Feasible
  - Chemically Unreactive With Other Components
  - Readily Available
  - 0.0 GWP (not required by Montreal Protocol)

early stages of this research work identified other potential blowing agents among hydrofluorocarbons (HFCs), cost considerations and availability, even in quantities necessary for R&D, seemed to argue against their use, narrowing choices, especially at that time, to the hydrocarbon (HC) isomers. In addition, HFCs have varying global warming potentials.

Therefore, in 1994, Atlas Roofing Corporation turned first to Europe as it began its pioneering research and development work to find a blowing agent with zero ODP. Europe had already successfully converted to HCs in the manufacture of polyurethane foam and seemed to offer some guidance and insight, although it was far from clear that HCs could be used in the manufacture of polyiso rigid foam. However, in 1994, on a European laminator, Atlas researchers produced the first prototype HC-blown polyiso roof insulation.

By 1995, Atlas had produced in the U.S. a laminated production rigid board and installed it in the first North American test roof incorporating HC-blown polyiso (Camp Hill, PA) and followed with a second test roof in 1996 (Meridian, MS). Samples removed from these roofs

indicated that HC-blown polyiso, even these early R&D products, could satisfactorily function in a roof system.

Table 2 shows data derived from testing specimens removed from these roofs at certain time intervals. The data show that these physical properties met recognized standards and maintained these values over five years. This was positive data but not especially surprising. However, the early evidence of outstanding thermal stability shown here—later shown to be unchanged between year two and year five—was noteworthy and led to further development and optimizing of formulations containing HC blowing agents.

By early 1998, Atlas had obtained the necessary classifications and approvals from Underwriters Laboratories (UL) and Factory Mutual Research (FM) to introduce zero ODP insulation and begin full-time production at one plant over four years ahead of the U.S. EPA deadline. As other Atlas plants followed, it became apparent that HCs would be the industry's choice for a third generation, zero-ozone-depleting blowing agent. At the time of this writing, Atlas has converted and is producing zero ODP insulation full-time at four plants. At least one other manu-

Property	ASTM C-1289-02	Initial Values	Two-year Values (Meridian)	Three-year Values (Camp Hill)	Five-year Values (Camp Hill)
Product Density ASTM D-1662	NA	1.98 psi	1.92 psi	2.06 psi	2.03 psi
Compressive Strength ASTM D-1621	20 psi (Grade 2)	21.24 psi	24.02 psi	23.5 psi	23.5 psi
Dimensional Stability (width) ASTM D-2126	2% (max.)	1.15%	1.13% (width)	1.09% (width)	1.05% (width)
k-factor	0.179 (after conditioning)	0.159	0.179	0.179	0.176

Table 2: Data courtesy of R&D Department of Atlas Roofing Corporation.

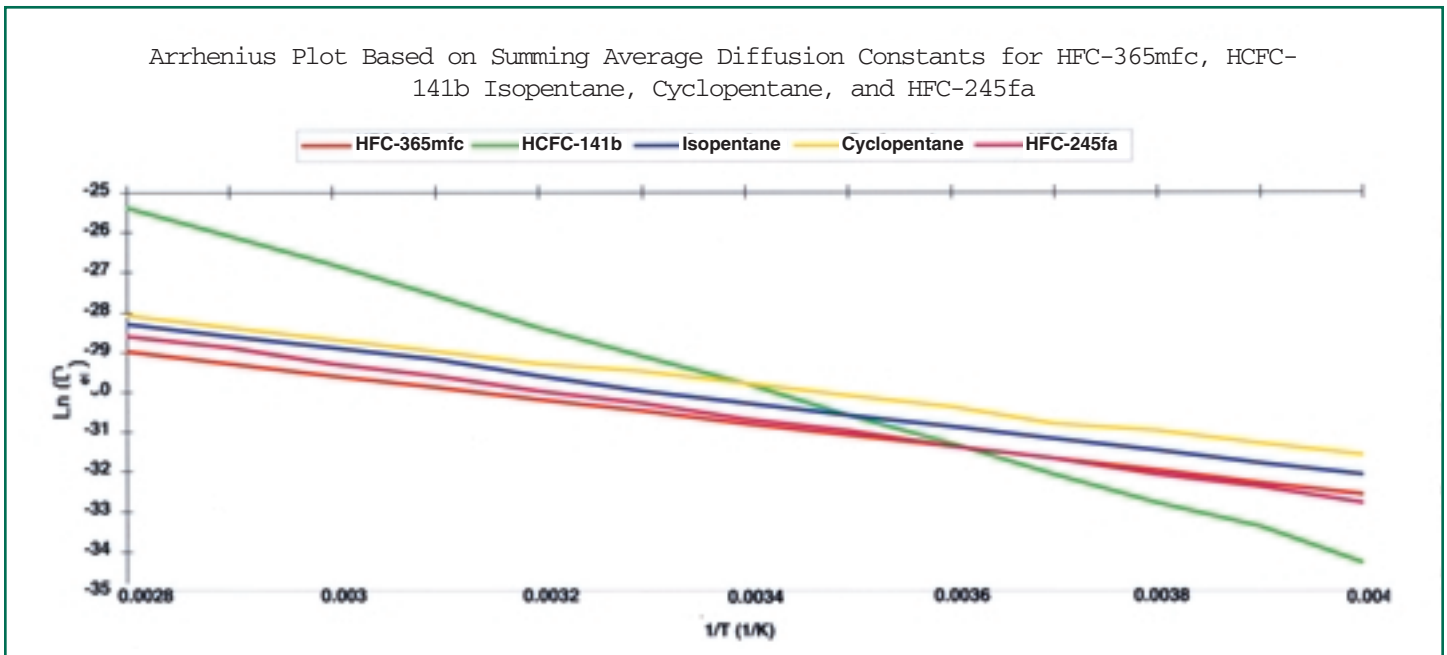


Figure 7: The Arrhenius plot provides a comparison of diffusion rates of different blowing agents with temperature changes.

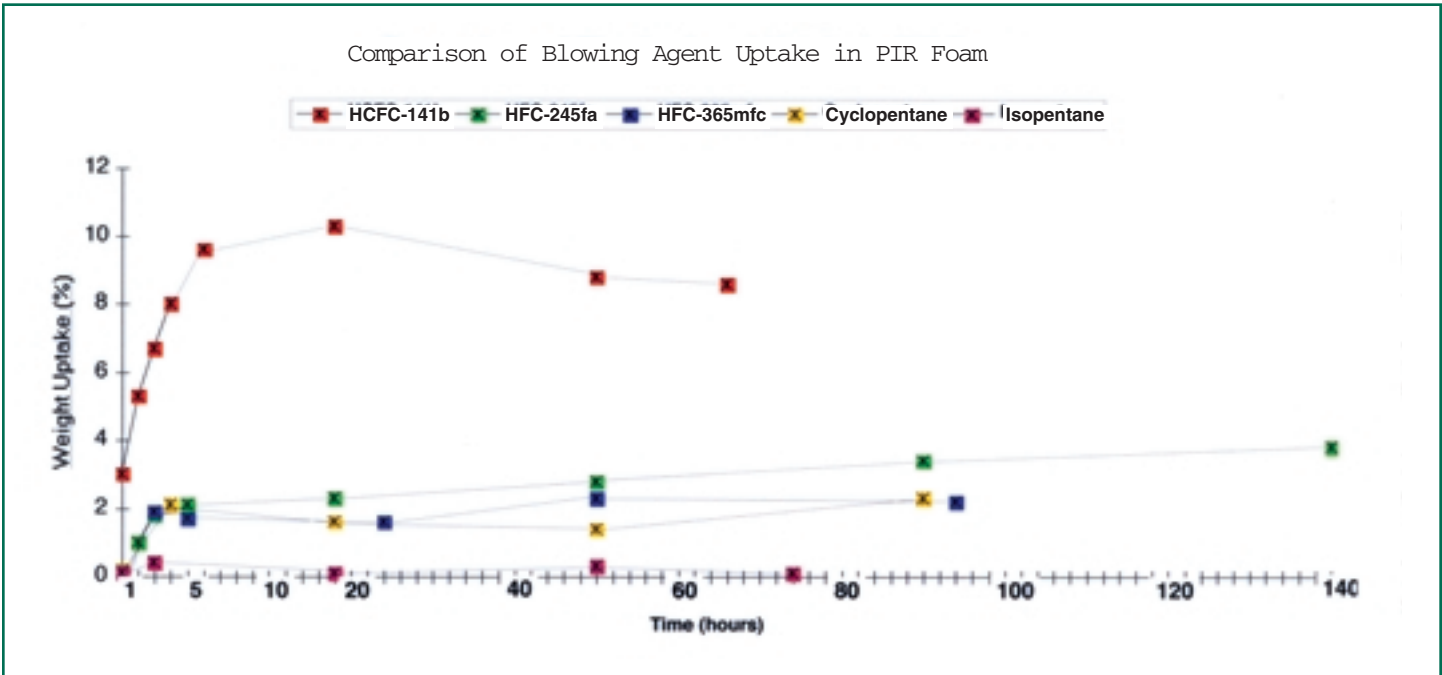


Figure 8: Comparison of blowing agent uptake in PIR Foam.

facturer is producing HC-blown foam full-time at one plant in Canada, and two other U.S. manufacturers have announced production conversion to a total of five plants. A fourth U.S. manufacturer has announced production capability.

### Blowing Agents and Thermal Stability

By 1997, studies that supported the R&D efforts already in place at Atlas began to appear in the literature and helped to explain the apparent thermal stability that Atlas noticed in these test roofs. ICI Polyurethanes Group (now Huntsman Polyurethanes) and ICI Europe Ltd. presented a paper at the Polyurethanes World Congress '97 focusing on ICI's work in developing predictive tools for long-term performance, including dimensional stability and thermal values.<sup>4</sup> These researchers identified several factors critical to long-term performance properties: blowing agent diffusion rates, blowing agent uptake in the polymer matrix, and foam morphology, including cell size and distribution, which are graphically illustrated in Figures 7 and 8.

Cell gas composition is affected by air entering or diffusing into the cell and by the blowing agent and carbon dioxide leaving or diffusing out of the cell. Diffusion rates, therefore, indicate the tendency of the blowing agent to leave the cell and the degree of change expected in cell gas composition. The Arrhenius plot shown in Figure 7 provides a comparison of diffusion rates of different blowing agents with temperature changes. It is important to note that the steepest curve in the graph represents HCFC-141b, and the curves of other blowing agents shown, including HCs, are more gradual, indicating a greater tendency for the HC blowing agents to remain in the cell.

Similarly, when the blowing agent is absorbed in the polymer matrix, it is no longer available as a low conductivity gas within the cell, changing the cell gas composition. Figure 8 shows the blowing agent uptake of polyiso foams expanded with various blowing agents. HCFC-141b has a relatively high rate of 9%,

compared to 0-2% for HCs, indicating its stronger effect as a solvent. Since the HC isomers have very low to zero solubility in the matrix, more of the blowing agent remains within the cell and helps to ensure long-term thermal stability.

### Foam Morphology

The vapor phase thermal conductivity of HCFC-141b (0.072) is lower than any of the HC isomers (0.083-0.104) [F.C.Rossitto, et. al.].<sup>5</sup> This presented a challenge to Atlas and to chemical suppliers since the conductivity of the blowing agent is

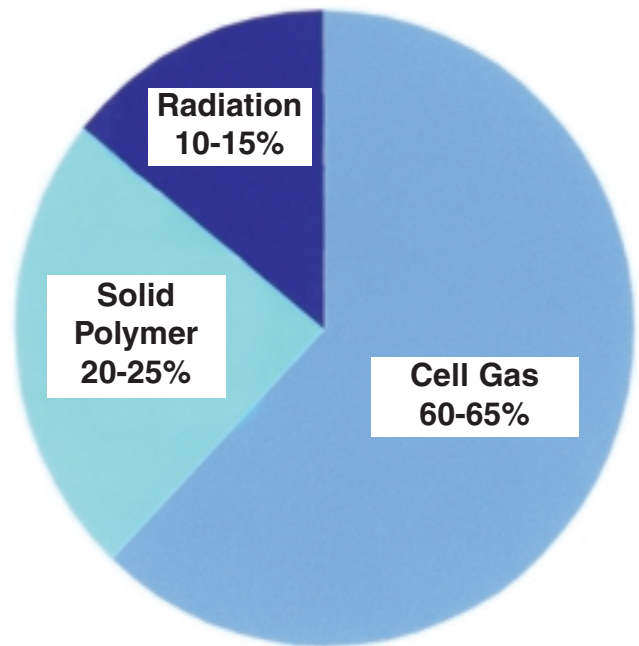


Figure 9: Cell size and closed cell content affect the thermal performance of the insulation.

important to the thermal performance of the insulation product. However, an examination of foam morphology, including cell size and distribution, helps explain the thermal efficiency of HC-blown foams despite the higher vapor thermal conductivity of HC blowing agents.

Cell size and closed cell content affect the thermal performance of the insulation. As shown in *Figure 9*, 60-65% of heat transfer of rigid foam is attributable to the thermal conductivity of the blowing agent and the overall cell gas composition (S.L. Schilling).<sup>6</sup> The remainder of the heat transfer is attributable to radiation (10-15%) and thermal conductivity of the polymer matrix (20-25%).

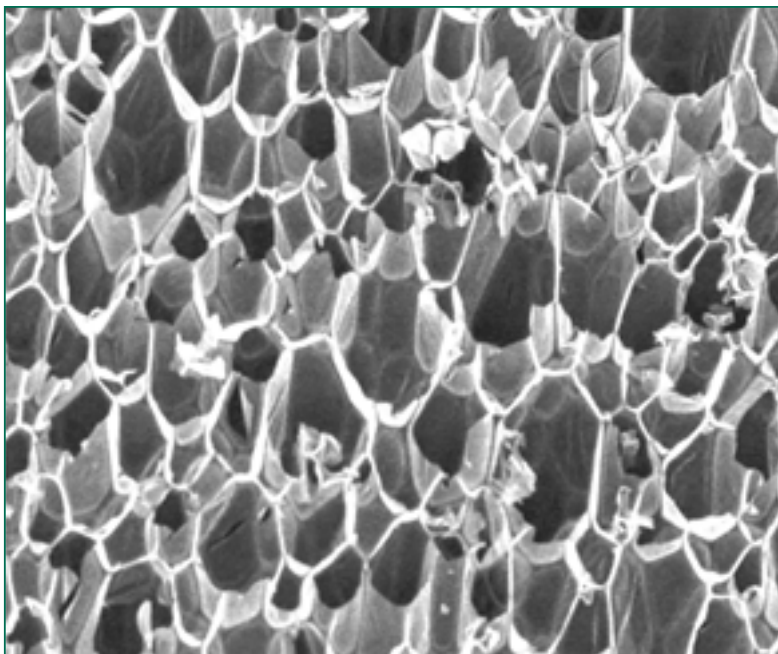
When cell size is reduced, the heat transfer attributable to radiation is also reduced because it is more difficult for heat to radiate across smaller, more numerous cells (Schilling). Thermal conductivity may also be improved by increasing the closed cell content, so that less blowing agent is lost through open cells. However, the closed cell content for HCFC- and HC-blown foam is typically 86-92%. Given these high percentages of closed cells, the rate of cell gas diffusion out of (or air into) the insulation by way of open cells is considered very low.

Instead of increasing closed cell content to improve the cell gas contribution to overall thermal conductivity, the lower gas diffusion and blowing agent uptake rates discussed above explain that more of the blowing agent remains in the cell, thereby maintaining long-term thermal conductivity. Conductivity through the polymer matrix can be lowered by reducing foam density, less polymer would be used in the foam. However, density ranges of commercially available polyiso roof insulation are currently necessary for overall foam stability. In addition, although a reduction in density might improve thermal conductivity, it could also cause larger cell size and lower closed cell content (Schilling).<sup>6</sup>

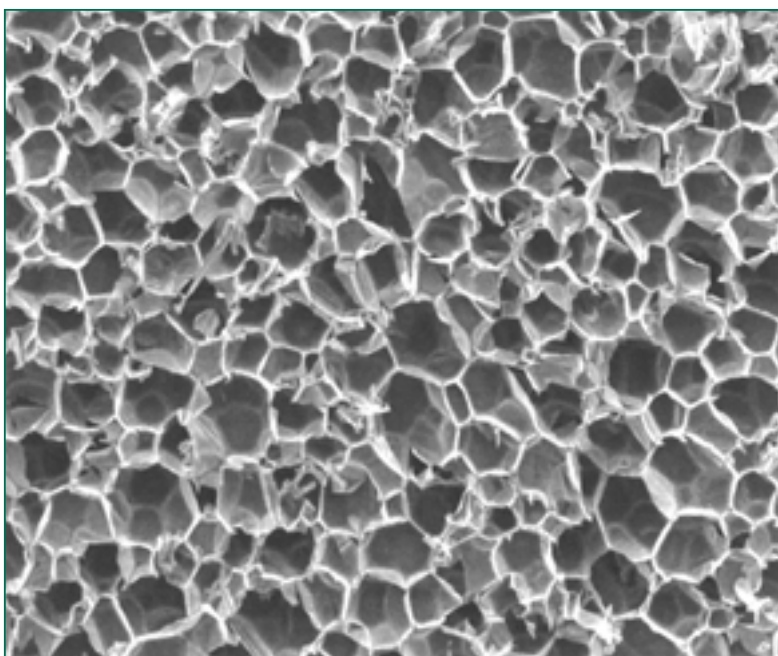
### Cell Size Analysis

As part of a recent Atlas R&D project, BASF Corporation performed cell size and distribution analysis on current HCFC- and HC-blown polyiso roof insulation. Foam samples were analyzed using SEM and Visilog Image Analysis software to determine cell size distribution. The data generated by this work further support the measured thermal stability of these early R&D foams. Sample 3 (*Figure 10*) is HCFC-blown foam and Sample 9 (*Figure 11*) is HC-blown. These samples were chosen because they were both sectioned and analyzed in the parallel to rise direction and contained the same number of cells in the photograph used for Visilog analysis. *Table 3* compares cell size length (largest dimension in any direction) in microns.

As explained by Schilling, the number and size distribution of cells significantly influence thermal conductivity; smaller cells minimize the radiation contribution to the overall thermal conductivity. Cell size differences are shown in the micrographs (*Figures 10 and 11*) and summarized in *Table 3*.



*Figure 10: The number and size distribution of cells significantly influence thermal conductivity. Foam #3. SEM image x50.*



*Figure 11: Cell size differences may be clearly shown in comparative micrographs. Foam #9. SEM image x50.*

The factors discussed above—lower diffusion rate, lower solubility in the polymer, and smaller cell size—explain the thermal stability of the early R&D foam. More recent testing on current

Sample	Mean (µm)	Median (µm)	S (µm)	Min (µm)	Max (µm)	# Cells*
3	264	251	75	168	475	36
9	191	185	50	108	323	36

*Table 3: \*number of cells in the photograph used for the Visilog analysis.*

Test Conditions	HCFC-blown Polyiso	HC-blown Polyiso
7 days, -29 °C, ambient RH	-0.02%	-0.02%
28 days, 70 °C, 97% RH	0.56%	0.67%
28 days, 80 °C, ambient RH	0.04%	0.04%

Table 4: Data courtesy of Atlas Roofing Corporation

production foam, however, reveals the same thermal stability seen in these early foams and dimensional stability values equal to HCFC-blown foams.

## Dimensional Stability

The above discussion of diffusion rates and blowing agent uptake focused on their importance regarding thermal conductivity. These factors can also affect dimensional stability because they influence cell gas pressure and plasticization (G. Biesmans, et. al.). Sufficient cell gas pressure, which can be diminished by blowing agent uptake and diffusion, prevents cells from shrinking and therefore plays an obvious role in maintaining dimensional stability. In addition, since blowing agent uptake or solubility in the polymer matrix can cause softening or plasticization of the foam, they can also affect dimensional stability.

However, based on test results using the standard dimensional stability test method (ASTM D-2126 Test Method for Response of Rigid Cellular Plastics to Thermal and Humid Aging), the change from HCFC to HC blowing agents had little effect. Since the test exposures prescribed in ASTM D-2126 do not replicate or approximate actual conditions within a roof assembly, the user of this standard is cautioned against applying the test results from a specimen to actual field performance of full-sized boards. However, it is a useful method for comparing relative dimensional stability values among specimens of plastic foam insulation and has proved reliable over the years as a QC tool. A linear dimensional change of 2% in length or width is the maximum value expected for polyiso roof insulation. Third-party laboratory test results of randomly selected samples are shown in Table 4. The hot and humid conditions were tested after 28 days instead of the 7 days prescribed in ASTM D-2126.

## Long-term Thermal Resistance

A new method (CAN/ULC-S770) for determining R-values of certain foam plastic insulations has emerged from Canada and

provides a long-needed definition of "aged" R-value, predicting both a 5-year aged value and a 15-year time-weighted thermal design value. It applies to polyurethane, polyiso, and extruded polystyrene, all of which "age." Since Canada adopted this method as a national standard, manufacturers there and in the U.S. have been testing products to determine their long-term thermal resistance (LTTR).

CAN/ULC-S770, "Standard Test Method for Determination of Long-Term Thermal Resistance of Closed-Cell Thermal Insulating Foams," based on ASTM C-1303-95, accelerates aging by a method called "slicing and scaling." Thin slices of foam [1/4 to 1/2 in. (6 mm to 12 mm)] age very quickly and are used to determine the number of days required before testing to predict the R-value of thicker materials. A version of this method has been included in ASTM C-1289-02, the faced polyiso standard specification, as a mandatory annex. By the end of this year, it is expected to replace the six-month conditioning procedure (now known as PIMA 101), which has been used for the past 20 years.

Table 5 shows long-term thermal resistance values for HC-

Thickness	LTTR-value 5-year aged	LTTR-value 10-year aged	LTTR-value 15-year aged	LTTR value 20-year aged
2.0 in.	12.3	12.1	12.1	12.0

Table 5: LTTR-values have been rounded up or down to the nearest tenth.

blown foam tested in accordance with CAN/ULC-S770. Samples of 2-inch polyiso were selected and tested by a third-party testing laboratory to determine the 5-year LTTR. In addition, the laboratory provided calculated predictions for 10, 15, and 20 year aged LTTR, using test data and the equation shown in Figure 12.

In this test, the 5-year predicted R-value is 12.3 for a two-inch polyiso board or 6.15 per inch of thickness. From five years through twenty years, the predicted LTTR drifts a mere 0.3 or 2.5%. All available data (from early R&D products in test roofs,

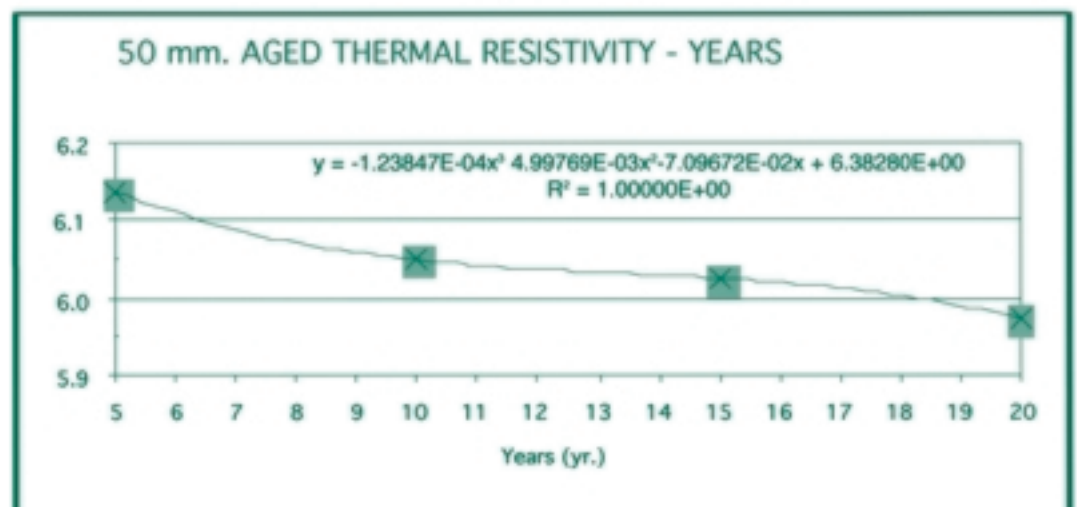


Figure 12: Calculated predictions for 10-, 15-, and 20-year aged long-term thermal resistance.



supported by gas diffusion rates and cell gas uptake rates, to many tests for long-term thermal resistance) indicate that HC-blown polyiso should be more thermally stable than previous generations of polyiso. Based on this data, over the life of a new roof or subsequent reroofs (when the polyiso insulation is often reused), the thermal performance of HC-blown foam would exceed that of HCFC-blown foam.

## Conclusion

Since the adoption of the Montreal Protocol in 1989, the polyiso industry has been on a path to products without ozone depletion potential. The first step occurred in 1993, when CFC-11 was replaced by HCFC-141b, which was considered an improvement because it had a lower ODP than CFC-11 and possessed other desirable characteristics. However, it was permitted only as a temporary substitute, as manufacturers sought a zero ODP replacement. After only nine years as a blowing agent for polyiso, HCFC-141b is slated for phase out on 1/1/03, amid some perceived uncertainty regarding the future performance of polyiso roof insulation.

This concern about the "new" blowing agent conversion seems generally unfounded, since the future of polyiso is already over four years old. Atlas Roofing Corporation introduced full-time production of HC-blown polyiso at one plant in August of 1998. Since then, HC-blown polyiso roof insulation has quietly accumulated a four-year track record in the U.S., approaching a billion square feet of installed product. When Atlas converted to HC blowing agents in 1998, unlike the Y2K experience at the close of 1999, something really did happen; it marked the introduction of zero ozone depleting polyiso roof insulation, improved thermal stability, and continued product performance. ■

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## AIA FINANCES IMPROVE DRASTICALLY

The American Institute of Architects, which last year projected a negative \$1.5 million in net assets for year-end 2001, has ended up with \$1.7 million in assets for that year and a projected year-end 2003 positive asset target of \$4.5 million. The turn-around was attributed to 1) the closing of the unsuccessful AECdirect web-based information and service product; 2) payment of only pennies on the dollar to creditors of AECdirect; and 3) \$1 million additional income from McGraw-Hill Construction, publishers of *Architectural Record*, to renew its publication contract through 2010.

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